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1 performance and indirect parameters. Further, there may be certain interactions between
2 parameters that may lead to variations in performance. Such variations may be positive or
3 negative influences on product performance.

4 The lots are typically identified by a lot number, called a component identifier herein,
5 which identifies the lot to the product manufacturer and the supplier, the component identifier
6 usually being used for accounting purposes or traceability to manufacturing parameters of the lot.
7 However, especially with small electronic components, the component identifiers themselves
8 may not be imprinted or bar-coded on the components themselves due to practical considerations
9 such as component size, or the extra time and expense in manufacturing that would be required
10 to do so. Therefore, once the components leave their packing materials in which they were
11 shipped, the lot from which those components came from may not be able to be identified.

12 Certain lots of components may be in some way defective or vary in their performance
13 due to the different manufacturing conditions referenced above, or due to a certain component
14 supplier's neglect or breach in promise to supply a certain quality of components. One solution
15 that has been employed heretofore is for the manufacturer to test statistically significant numbers
16 of components from each lot as they arrive from the individual suppliers. However, with
17 products that are sold for low profit margins, such testing and delay in product assembly has
18 become untenable. More and more product manufacturers have been forced to rely on
19 component suppliers' representations that the supplied components meet the standards set by the
20 product manufactures, or that the supplied components fall within a set standard deviation of
21 performance within each lot. Such reliance has proven inadequate in countless situations, with
22 many product manufactures having their products show variations in performance when it is too
23 late to trace the suspect components back to the lot from which they came.

24 Still, apart from the components themselves, there may be product manufacturing
25 parameters which may be responsible for variations in performance in products. For example,
26 the temperature or humidity of a factory where the components are assembled into the products

1 may be a contributing factor to product performance. Other product manufacturing parameters
2 such as the assembly line or conveyor belt speed may further affect product performance.

3 Solutions to the above problems are described in U.S. Patent Application Serial No.
4 09/494,175, filed January 31, 2000, entitled METHOD USING STATISTICALLY ANALYZED
5 PRODUCT TEST DATA TO CONTROL COMPONENT MANUFACTURING PROCESS

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6 which is hereby incorporated by reference herein. That application provides for a plurality of
7 analytical tools for identifying correlations between products which show variations in
8 performance and product or component manufacturing parameters. Typical analytical tools
9 which are described in the system of that application include statistical data tools, a data
10 visualization tool, a data-mining tool, an on-line analytical processing (OLAP) tool, an
11 information broadcast tool or some combination thereof. However, typical analytical tools
12 require that the operator of such tools have a working knowledge of which manufacturing
13 parameters may cause product performance to suffer. The programmer is then required to
14 program the operation of a particular analytical tool based on predicted manufacturer parameter
15 anomalies. As a result, unpredictable anomalies may thus go undetected, or may be difficult to
16 pinpoint.

17 Finally, it is often difficult to ascertain normal operation of a product relative to a
18 manufacturing parameter as compared with anomalous operation. This is especially so with
19 respect to multi-variant manufacturing parameters which may have anomalies in one or more of
20 several performance measure dimensions. For example, one or more configurations of a disk
21 drive head assembly may have anomalous operation with respect to seek time while having a
22 relatively low error rate and normal servo tracking. Given that other head assembly
23 configurations may show anomalous performance in seek time, error rate or servo tracking,
24 defining just what is normal operation can be difficult, much less identifying anomalous
25 operation.

26 Thus, there is a need for a system and method for defining normal operation in product
27 performance with respect to manufacturing parameters in multiple dimensions. There is further a

1 need for a system and method for identifying unpredicted or unpredictable manufacturing
2 anomalies.

3 **SUMMARY OF THE INVENTION**

4 A method and system for identifying manufacturing anomalies in a manufacturing system
5 comprising a plurality of products which are manufactured with a plurality of manufacturing
6 parameters is disclosed. The system comprises a data mining program applied to the data
7 warehouse for analyzing the stored manufacturing parameters to define a normal manufacturing
8 parameter subset. The data mining program is further for detecting that at least one of the
9 plurality of manufacturing parameters is excluded from the normal subset. The system further
10 comprises a reporting means for reporting the at least one detected manufacturing parameter.

11 The data mining program may further detect that a plurality of the manufacturing
12 parameters are excluded from the first subset. The data mining program then analyzes the
13 detected plurality of manufacturing parameters to define a second normal subset of the detected
14 plurality of manufacturing parameters. The reporting means may then report the second normal
15 subset of manufacturing parameters.

16 The data mining program defines a normal subset by first classifying performance
17 variables in n-dimensional space. The manufacturing parameters are plotted against various
18 performance values. The data mining program defines one or more performance clusters, or
19 subsets, of parameters of products which show similar performance ratings in the n-dimensional
20 space. The data mining program is then able to detect parameters which fall outside the groups,
21 thereby defining an anomaly in performance for that parameter.

22 **BRIEF DESCRIPTION OF THE DRAWINGS**

23 Fig. 1 is a flow diagram illustrating the steps performed by the system of the present invention;
24 Fig. 2 is a block diagram showing an exemplary structure of a system that performs the method
25 illustrated in Fig. 1;
26 Fig. 3 is a simplified n-dimensional space plot of manufacturing parameters based on product
27 performance produced by the data mining program of the system of Fig. 2;

1 Fig. 4 is a simplified n-dimensional space plot alternative to that shown in Fig. 3;
2 Figs. 5-6 are visual representations of one of the methodologies used in the overall categorization
3 performed by the data mining program of Fig. 2; and
4 Fig. 7 is an output from another visualization tool of the data mining program 54 similar to that
5 illustrated in Fig. 4.

6 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

7 With reference to Fig. 1, a flow diagram illustrating the steps performed in a method for
8 identifying manufacturing anomalies in a plurality of products which are manufactured with a
9 plurality of manufacturing parameters in a manufacturing system described in Fig. 2 referenced
10 below is shown. The plurality of manufacturing parameters (20 in Fig. 2) are stored in the data
11 warehouse (56 in Fig. 2) step 300. A data mining program (54 in Fig. 2) is applied to analyze
12 the stored manufacturing parameters 20 to define a first normal manufacturing parameter subset
13 (102 in Fig. 3 described below), step 302. The first normal subset 102 is defined by categorizing
14 the manufacturing parameters 20 in n-dimensional space (100 in Fig. 3). The data mining
15 program 54 detects at least one of the plurality of manufacturing parameters 20 that is excluded
16 from the first normal subset 102 in the n-dimensional space 100, step 304. The detection of the
17 at least one manufacturing parameter 20 is then reported to personnel through a notification
18 system (70 in Fig. 2), step 306.

19 The data mining program 54 may detect that a plurality of the manufacturing parameters
20 20 are excluded from the first normal subset 102, step 308. In this case, the data mining program
21 54 may analyze the detected plurality of manufacturing parameters 20 to define a second normal
22 subset (106 in Fig. 3) of the detected plurality of manufacturing parameters 20, step 110. The
23 second normal subset 106 is defined by the data mining program 54 by categorizing the
24 manufacturing parameters 20 excluded from the first normal subset 102 in the n-dimensional
25 space 100. The notification system 70 then reports the second normal subset 106 of
26 manufacturing parameters 20 to personnel, step 312.

1 With reference to Fig. 2, an exemplary structure of the system for identifying
2 manufacturing anomalies in a manufacturing system is shown. The system includes a
3 manufacturing information system 51 for a manufacturer 50 such as the above-referenced U.S.
4 Patent Application entitled METHOD USING STATISTICALLY ANALYZED PRODUCT
5 TEST DATA TO CONTROL COMPONENT MANUFACTURING PROCESS. The system
6 includes a data warehouse 57 for storing product identifiers 56 identifying products having
7 manufacturing parameters 20 and values representing the manufacturing parameters 20. The
8 manufacturing parameters 20 may comprise product manufacturing parameters and/or
9 component manufacturing parameters.

10 A data mining program 54 is applied to the data warehouse for analyzing the stored
11 manufacturing parameters 20 to define the first normal subset 102 of manufacturing parameters
12 20. The data mining program 54 detects that at least one of the manufacturing parameters 20 is
13 excluded from the normal subset 102.

14 A reporting means, comprising a notification system 70, is included for reporting the at
15 least one detected manufacturing parameter 20 to personnel.

16 A relational means 58 is provided in the data warehouse for relating the manufacturing
17 parameters 20 with particular product identifiers 56 for products that have the related
18 manufacturing parameters 20. The relational means 58 may comprise an RDBMS system such
19 as that produced by ORACLE Systems of Redwood Shores, California or by NCR of Dayton,
20 Ohio.

21 The system includes a means for receiving 60 product performance data 80, wherein the
22 performance data 80 includes product identifier data for matching with the product identifiers 56
23 in the data warehouse 57. The means for receiving 60 may comprise a data terminal and
24 keyboard, personal computer or failure analysis test equipment for receiving data from failed
25 products.

26 The data mining program 54 is applied to the data warehouse 57 for defining a normal
27 subset by first classifying performance variables in n-dimensional space as described with

1 respect to Fig. 3 below. The manufacturing parameters 20 are plotted against various
2 performance values. The data mining program 54 defines one or more performance clusters, or
3 subsets (102-106 in Fig. 3), of manufacturing parameters 20 of products which show similar
4 performance ratings in the n-dimensional space. The data mining program 54 is then able to
5 detect manufacturing parameters 20 which fall outside, or are excluded from, a subset 102,
6 thereby defining an anomaly in performance for that manufacturing parameter 20. Further, a
7 new subset 106 may be defined by the data mining program 54 from performance clusters
8 defined by a plurality of manufacturing parameters 20 excluded from the first normal subset 102.

9 The data mining computer program 54 may comprise a plurality of data mining sub-
10 routines 59 for executing. One or more of the sub-routines 59 may be executed to define one or
11 more first normal subsets 102 of the manufacturing parameters 20. Another data mining sub-
12 routine 59 may be used to detect that one or more parameters 20 fall outside the one or more
13 normal subsets. Another sub-routine 59 may be executed for analyzing the detected
14 manufacturing parameters 20 to define new normal subsets 106 from the detected plurality of
15 manufacturing parameters 20. Each sub-routine 59 may be divided between a plurality of
16 executable files for executing against the data warehouse 57.

17 With reference to Fig. 3, a simplified plot in n-dimensional space 100 of manufacturing
18 parameters 20 based on product performance produced by the data mining program 54 of the
19 method of Fig. 1 and system of Fig. 2 is shown. For the n-dimensional space 100 of Fig. 3, $n=3$
20 in order to simplify the diagram for illustrative purposes. The dimensions may represent error
21 rate, access speed, and yield for disk head assemblies. Each axis in the n-dimensional space 100
22 of Fig. 3 represents the scale for a dimension. As described above, the data mining program 54
23 has defined a normal subset 102 based on performance data 80 received from the input means 60
24 plotted against each axis. At locations 104 in the n-dimensional space 200, a plurality of
25 performance parameters 20 are separated from the normal subset 102. The data mining program
26 54 has further defined other normal subsets 106 in the n-dimensional space 100 with
27 performance parameters that are separated from the normal subset 102.

1 With reference back to Fig. 2, a notification system 70 causes persons to be notified when
2 either a performance parameter 20 (location 104 in Fig. 3) is excluded from the normal subset
3 102, or a new normal subset 106 (locations 106 in Fig. 3) is found by the data mining program
4 54. When the system requires reporting to users, a personnel notification identification database
5 (PNID) 72 is consulted. In the embodiment of Fig. 2, the PNID 72 comprises a plurality of
6 PNID parameter records 20a that each match up to one of the parameter records 20 in the data
7 warehouse 57. If a manufacturing parameter 20 is identified as being excluded from the normal
8 subset 102, or a second normal subset 106 is identified and defined by the data mining program
9 54, then the system matches all of the identified manufacturing parameters 20 with the
10 corresponding PNID parameter records 20a in the PNID 72.

11 The PNID 72 further contains personnel records 76. The personnel records 76 each
12 identify one or more persons to be notified when one or more PNID parameter records 20a are
13 matched with the identified manufacturing parameters 20. The PNID parameter records 20a are
14 related to the personnel records 76 through a relational means 78 such as that described above
15 with respect to relational means 58.

16 A notification method database (NMD) 82 within the notification system 70 is next
17 consulted to determine the method 700 by which each person identified by each personnel record
18 76 should be notified. The NMD 82 contains notification method personnel records (NMPRs)
19 76a stored therein which are readily matched with the personnel records 76 of the PNID 72.
20 Each NMPR 76a is related with at least one of a plurality of method records 702a-708a through a
21 relational means 88 such as that described above with respect to relational means 58 above. Each
22 method record 702a-708a designates a method of notification 700 which the notification system
23 72 acts upon to provide notification to personnel. For each person who is to be notified, as
24 indicated by matching the personnel records 76 that are related to PNID parameter records 20a
25 that are matched with identified manufacturing records 20, the related method records 702a-708a
26 indicate to the notification system 70 how each person should be notified. In the embodiment of
27 Fig. 2, method record 702a indicates that electronic mail 702 should be used to notify the

1 specified person, method record 704a indicates that voice mail 704 should be provided, method
2 record 706a indicates that a page 706 should be issued and method record 708a indicates that a
3 person should be notified by cell or wireless phone 708.

4 The above described actions of the notification system 82 may be executed by a
5 combination of hardware in conjunction with a notification program 84. A personal computer
6 with an RDBMS stored therein may comprise the notification system 70.

7 With reference to Fig. 4, another embodiment of a simplified plot of manufacturing
8 parameters 20 in n-dimensional space 100 based on product performance produced by the data
9 mining program 54 of the method of Fig. 1 and system of Fig. 2 is shown. For the n-dimensional
10 space 100 of Fig. 3, $n=3$ in order to simplify the diagram for illustrative purposes. As with the n-
11 dimensional space 100 of Fig. 3, the dimensions may represent error rate, access speed, and yield
12 for disk head assemblies. Each axis in the n-dimensional space 100 of Fig. 3 represents the scale
13 for a dimension. The data mining program 54 has defined a normal subset 102 based on
14 performance data 80 received from the input means 60 plotted against each axis. However, in
15 Fig. 3, the normal subset 102 forms a surface instead of a cluster. At locations 104 in the n-
16 dimensional space 100, a plurality of performance parameters 20 are separated from the normal
17 subset 102 surface. The data mining program 54 has further defined other normal subset 106
18 surfaces in the n-dimensional space 100 with performance parameters that are separated from the
19 normal subset 102 surface.

20 Fig. 5 is a visual representation of one of the methodologies used in the overall
21 categorization performed by the data mining program 54 to determine normal and abnormal
22 subsets. This particular form of the data mining program 54 presents a categorization that is
23 called a decision tree because of branching that takes place to categorize and subset groups of the
24 manufacturing parameters 20. A base root node of the tree (barplot at the front in Fig. 5) shows
25 the response variable (e.g., yield) plotted by quantity within bins (e.g, number of products with
26 yields from 0-5%, 5-10%,95-100%). At the base of this root node, the data mining program
27 54 lists a most significant manufacturing parameter (in the n dimensional space 100) for

1 grouping the yield into distinct (non overlapping) groups (similar to groups 102 and 106 in figure
2 4). The conditions applied for the grouping are published by the data mining program 54 (e.g.,
3 total product returns ≤ 18 for the left branch, total returns >18 for the right branch) - and are
4 shown in Fig. 6 for one of the branches. Fig. 6 also shows the distribution of a subset (note this
5 subset consists strictly of high valued devices – no low valued ones are present).

6 This process is repeated for each subset until the data mining program determines 54 that
7 no statistically significant improvement in segregation can be made. Thus in terms of Fig. 4,
8 there would essentially be 7 terminal nodes representing groups 102, 106 and up to 5 individual
9 nodes representing the independent outliers represented by 104 in figure 4.

10 Fig. 7 is an output from another visualization tool of the data mining program 54 similar
11 to that illustrated in Fig. 4. The plot in Fig. 7 illustrates up to 5 dimensions by varying the x,y,z
12 positions, the color of the clusters, or balls, and the opacity of the balls. In addition the size of
13 the balls is proportional to the quantity of units in each subset 102, 106. This visualization tool
14 may be used by the investigator to verify the statistical groupings made by the data mining
15 program 54 like in Fig. 4.